A PILOT COURSE IN ENGINEERING SYSTEMS ANALYSIS

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Central Intelligence Agency
Washington, D. C. 20505

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EVENT 66

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Abstract

The requirement for continuing education particularly in the rapidly changing systems environment is a well recognized fact. The methods for best meeting this requirement, however, are not as clearly understood. In an attempt to reduce this disparity, this paper presents a complete description and analysis of an on-site pilot course in Engineering Systems Analysis that was recently held internally in a government organization. The motivation for presenting the course along with its organization and implementation, and an assessment of its success are discussed in detail. A number of innovations which were included within the course framework are evaluated from both the student and teacher/administrator viewpoints. In particular, the methods used for the course design, organization, communication and modification are discussed along with the presentation of a comprehensive course outline. One of the most important conclusions reached is that through careful organization, continual contact, and interactive participation and guidance by the students, the instructor and most importantly by experienced members of the organization in question, a viable framework of continuing education in systems engineering may be fostered.

INTRODUCTION

In industry and in government, it is common management practice to form large multidisciplinary working groups of engineers and scientists on a project or system oriented basis. The term "matrix organization" is currently used to describe the functional and management personnel involved in this type of structure. Within the structure, a process of iterative design between subsystems is established whereby an attempt is made to reach the project objectives. By continually interacting and adapting, the organization converges on a solution which although not ideal perhaps for any one subsystem, presumably represents an optimum for the totality of subsystems or for "the system." This iterative process of examination within the structure is generally entitled Engineering Systems Analysis.

In a large matrix organization, it is almost impossible for any one project manager or team member to achieve intrinsic mastery of the many disciplines represented within the team. This fact results from both the breadth and dynamic nature of the material. However, it is possible for a generalized analysis approach to be structured and for an educational program to be developed to facilitate the extraordinary amount of multidisciplinary communication required within the structure. In this light, the purpose of this paper is to present a description and analysis of an on-site pilot course in Engineering Systems Analysis that was recently presented in one government organization. The attempt of the course was to present a sequence of material that although less than "all things to all men" offered assistance in the fundamental understanding and communication required for effective organization performance.

CURRENT CHALLENGE

At this point one must question the basic need for Engineering Systems Analysis. After all, the notion of an interdependent set of major subsystems being engineered artfully into a harmonious whole, is not at all new. The early marriage of the gangplank to the trireme by the Romans around 250 B.C. is one of the earliest examples of good subsystem compatibility. More currently, however, after a decade of warm acceptance, both the value and the concept of "systems engineering" practices are being questioned today. Representative of this current challenge is an article by Secretary Robert Frosch[1/] which urges that more engineering judgment be factored into methodology. In general, Frosch states that rote practice of systems engineering has led to an overemphasis on supportive impedimenta such as configuration management, reliability, PERT and milestone schedules, and complete logistics and programming tools for the operation of a vehicle (system) which has not undergone proper engineering design. In the process, the crucial core technical factors have competed at a disadvantage with systems priorities and jargon. In Frosch's opinion, this must change for the emerging systems of the future as they become more technologically complex.

MODEL SYNTHESIS

One method of shifting the balance between systems impedimenta and technological factors appears in the approach suggested by Chestnut.[2/] He presents a series of major precepts which are basic to the systems approach. In these precepts, the central thought is that it is quicker and more efficient in most designs to generate a small-scale mathematical model or system simulation. With this model as the focus of the design, the requirements of performance, component perturbation, parameter sensitivity and error allowances may be readily evaluated with a minimum of impedance. One might also add that the model yields dynamics of the various subsystems operating separately or together and provides easy identification of the subsystem interfaces which may be independently studied. Reinforcing this opinion, Draper[3/] states that the advantage of a systems model in all fields is that it seems to offer a unitary approach to the attack on complex interactive problems. For example, he indicates that such quantities as environmental design factors may be included as a subsystem add-on.

REMAINING PROBLEMS

Even if one accepts the modeling concept as a beneficial approach to engineering systems analysis, in view of the challenge facing it, problems still exist. "There has always been a shortage of persons who can conceive, design and develop the complex systems demanded by the new technologies."[4/] In addition, there is widespread recognition of the need for a better balance between the technical problem-solving role involving engineering judgments and the standard procedures and decision oriented tools associated with project management. A fundamental understanding and communication of these seemingly different but actually quite similar processes is seldom found.

Finally, there is evidence that problem-solving within a systems organization would improve in quality by providing technical people with a multi-field set of tools.[5/] Frishmuth and Allen propose a model for the technical problem-solving process. They noted that the engineer employed on a problem, rapidly becomes insensitive to acceptance of new alternatives as he becomes positively biased toward a particular technical approach. He thus develops a higher threshold as soon as confirming information is received for a particular route to problem solution. "Openness to additional cues is drastically reduced and is either normalized or gated out." It would follow that the basic solution approach might be enhanced by providing the worker with the ability to translate between fields of technology with a wider range of technical alternatives being made available at the beginning of the problem-solving process.

Further data on the problem-solving mechanisms were developed by Allen and Marquis.[6/] Their controlled experiment covered five laboratories working on the identical problem, and three separate laboratories working on a second problem. Conclusions of the study were that prior knowledge or experience with techniques appropriate to the problem, generally resulted in a positive bias regarding the solution. The converse was also true to result in a negative bias to successful solution. For the negative bias case, where a second alternative was considered, the probability of success was raised from zero to a half.

The effects of training and experience on technological transfer is discussed by Gruber and Marquis.[7/] Internal sources in a total organization were more effective for technical transfer in contrast to reliance upon outside consultants or upon externally contracted research.

Finally, experience has shown that a group of common tools may be identified which are relevant to most systems models. These tools generally accommodate several major disciplines including optics, acoustics, electromagnetics, and seismics as well as human engineering and biomedicine.

If leading publications of these fields are culled, a pattern of commonality in the mathematical modeling may be noted to exist beneath the semantic language of the particular field. This would imply that if symbology and approach were systematized for a set of applications, then complex sets of problems in individual technical fields would be tractable to a more catholic approach. Examples are found in transformation, matrix manipulations, numerical methods, statistics and probability, etc. Beyond these basic tools, there is a set of subsystems commonly used in systems design for all of these disciplines. Detection and decision-making functions, spatial or multisensor processing, servomechanisms and modulation codings serve as common examples.

COURSE DEVELOPMENT

In view of the above discussion, the role of continuing education in the systems area becomes apparent. Not only does it present an opportunity for preventing premature technical obsolescence; it also presents an opportunity for enhancing required communication and developing more competent well versed systems engineers.

The role of continuing education in systems analysis is apparent; however, once a decision is made to develop a course, the fundamental problem of developing a useful course content becomes paramount. This content is required to tread and exploit the common ground between the various disciplines

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commonly found within system matrix organizations and yet acquaint each with the individual intricacies of the other. In the present case, a review of this problem indicated that the most logical approach was that of tying together the information processing discipline, if it can so be called, as modified for multiple subsystems. In this discipline there has been a remarkable transition over the past five years in both industry and government. In general, its methods and techniques have evolved as the common core of systems analysis with a typical scientist or engineer with advanced degrees in mathematics, computers, electrical engineering or experimental psychology well familiar with its essentials. Since people of these background generally form the overwhelming majority of systems analysts, it follows that information processing represents a reasonable core discipline. In addition, it may be parenthetically noted that the advent of computers and the need for more fundamental statistical analyses has also acquainted many other fields, such as mechanical and industrial engineering with the essential elements of information processing.

The evolution of information processing as the core or fundamental model of systems analysis may generally be explained as the convergence of three main fields to effectively common problem types. The source fields have been mathematics, experimental psychology, and electrical engineering.

Because of their relative independence, each has developed its own symbology techniques and problem solving approaches. When cast together as a systems analysis team, however, the differences in "language" become a major subsystem communication barrier. For example, the "type one and type two errors in a two person zero sum game" discussed by a mathematician become the "false-alarm and detection probabilities" when viewed by the electrical engineer. Thus, even though the core exists, the need for presenting a common interpretation remains. The premise is made that an engineering systems analysis course is one vehicle for developing this common interpretation. The fact that technology is continually evolving further necessitates the need for such a course.

An in-house continuing education course appears to present an excellent opportunity for high performance since the course design may be tailored directly to suit local "cultural" factors. A visceral set of quick feedback loops exists within the organization to correct the course both in material and presentation. However, experience has shown that for success in a continuing education course a number of factors must be considered irregardless of its content. Before presenting the course outline, let us first present our considerations on these auxiliary problems.

MOTIVATION

Regarding attitudes towards continuing education, a recent NSPE (National Society of Professional Engineers) survey[8] showed that of 2,500 respondents, about 55% had taken programs of continuing education. Of these, 41% has been motivated by the hope of further professional advancement. Continuing educational studies outside advanced degree programs were seen as a requirement by ASEE to be met by the profession and by academic institutes. "It is a matter of taking a long range look at the ever increasing rate of technological change and then deciding what now needs to be done to assure that continuing effectiveness of the profession in the 1970's and beyond."

The advanced degree program was studied by Ruben and Morgan.[9] Supplementary training was pursued in an inverse proportion to the formal educational attainment for the group studied. The higher the degree, the less likelihood of participation in supplemental training. The problems of motivation were studied. A group of 370 engineers and scientists at the Langley NASA Research Center were polled. Control groups were:

(a) Those who received the MS degree version of the test questionaire.

(b) Those who received the 7-courses version.

(c) Those who received the 1-course version.

The test procedure was a rating of individuals on a semantic-differential scale; the scale consisted of 15 adjective-pairs, rated from 1 through 7. Typical pairs related to perception of an individual such as: scientific or non-scientific; poised or awkward; aggressive or timid; high initiative or low initiative; etc.

The results of this test showed that there was little perceived difference in performance between the MS group and the 7-course group. There was significant difference between the 1-course group and the others. Otherwise stated, the results were that individuals who had participated outside in over 7 courses were perceived as preventing technical obsolescence in themselves; the outside effort was perceived as a route to organizational advancement.

TIME ALLOCATION OF TECHNICAL SUPERVISORS

For an effective in-house program it is relevant to examine the relative amounts of time allotted under pressure by the technical supervisor. This is highly meaningful because for sustained attendance one must have the backing of the individual supervisors. The effort of the individual in the course is influenced by his perception of how his supervisor wishes him to allocate his own training effort.[10] One technical organization in DoD, of about 800 technical personnel, showed that first-line supervisors (57) felt that a 15% time allotment was average for "advising and training" subordinates. For second line supervisors, (24), a 10% allocation was given. For laboratory managers, the highest level in the organizational hierarchy, (8) an allotment of 11% was cited. For continuing training by itself, an allocation of 9:5:5 percentage respectively was observed.

A nominal 5% was felt to be a practical time commitment for the course. A positive reinforcement was felt to be visible in allotting 1 day per 4 weeks for a full day seminar session. It was attempted to have this day fall on the same day of the week and the same week each month. It was attempted to provide consistency in classrooms, format and class notes. Continuing contact between sessions was designed to be maintained via several means. Home problems, detailed handouts from the problem solutions,conversations through the month with both students and group leaders, special handouts and reprints of technical literature were made to maintain a continuing contact. An intermediate 2-hour problem solving session was held midway between the full-day sessions. Additionally, a visible response was attempted to any suggestions or interactions by the students or their supervisors. The full-day session was arranged in a round table format; a class note packet was received by each student approximately 5 days prior to the session. A chalk board development was intentionally made in a pictorial formulation by the instructor. Morning periods were intended to cover basic development of the particular topical area and to delve into the system theory pertinent to the particular subject. The early afternoon period was used for a detailed in-house application example; a high degree of relevance was possible here by working with the "guest" lecturers about 2 weeks in advance. The late afternoon period consisted of a second-level approach to the earlier base material. This was intended to allow for heterogeneity, the student background and interest.

POLL FOR ESTABLISHING CONTENT

As an initial step in framing the substance of the course, a questionnaire was circulated to a representative government group. Comments were asked on preferred timing and on background; the main thrust of the poll, however, was to indicated areas of perceived strengths and weakness in a set of 12 topical groups. Table I lists the 12 areas and the indicators for each, which were framed using the Miller listing.[12] The actual list cited in this reference was paraphrased and modified somewhat to accommodate to general system needs. Where a respondent singled out an area as a weak personal point or as a strength, in a definitive way on the returned questionnaire, the count was accrued. A profile of internally perceived competence may be inferred from the cumulative data. This in turn was used to frame the content of the course. There is no correlation with respondents and the numbers of strengths or weaknesses cited, since overlapping subsets are present. However, it was felt that a relative mix of about 50% "subsystems" would be appropriate following a 50% time allocation to the more basic building blocks. Table II lists the total distribution of degrees. The four non-degree respondents had more than 2 years of college in technical fields; the advanced degrees shown usually were for respondents who had also achieved earlier prerequisite degrees. (No professional degrees were noted.) It had been expected that the interested group would be diverse both in level and in field.

TABLE I

Number of Indicators--Strong/Weak Among Respondents

Weak Indicators		Strong Indicators
7	Complex Variables, vector analysis, operators, matrix operations, related material. Problem Groups: basic, first session introductory--sample signals	15
6	Operational Calculus, integration; matrices; line integrals; Rieman space; common operators. Problem Groups: basic; review--sample signals	9
12	Elementary Probability, Stieltjes Integral, common distributions, histograms, independence, tests for dependence, averaging, clipped data, analog data, stationarity. Problem Groups: noise models, signal models; zero crossover, amplitude uncertainty, quantization, sampling	11
17	Applied Engineering Statistics, signal detection probability, conditional probability, common distribution, switching, prediction, filtering parameters, moments. Problem Groups: noise models for environments, processors, source inputs	12
21	Correlation, discrete and continuous, cross correlation tests, goodness of fit, significance, tau translation benefits, reconciliation of statistical approach, orthogonality, independence, error analysis. Problem Groups: noise models, signal models, approximation	1
10	Transforms, Fourier, Walsh, Laplace, clipping, analog, digital data, Z transforms Tou transforms. Problem Groups: transient and steady state responses, noise estimates	6

12	Transforms, Hilbert, Fresnel, common kernel integrals . Problem Groups: spectrum shading, multipath transmissions, media	3
7	Servo System Analysis, flow analysis, sensitivity, feedback, transfer function, impulse response, error representation, statistical approach, smoothing and filtering, prediction compensation input/output relations. Problem Groups: signal input/output consideration, collection analysis techniques control systems, guidance devices	8
10	Fields and Wave Phenomena, array configuration, gain, spacing, shading, phase, signal/noise matrices, near fields, far fields Problem Groups: arrays for sensors, sidelobe exploitation, notching, spatial filtering, ranging, localization, holography, lens design, matched filters	4
10	Detection/Optimization, detection theory, tests criteria, minimax, likelihood ratio, false alarms/dismissals, Wiener-Hopf filters, optimum recovery, sequential. Problem Groups: detection devices, operator aids	1
8	Bayesian Statistics, error probabilities, average cost minimizing, thresholding, complex nets Problem Groups: PR devices, ATR state definition, event indicators, system design	1
7	Modulation, am, fm, ppm, pam, pcm, digital, noise immunity, common error codes, redundancy, error rate estimates, polynomials error codes, fading channels. Problem Groups: telemetry, coding, data transmission, security	8

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TABLE II

Distribution of Academic Degrees Among Respondents

none (supplemental schooling)	4
BS, BA	38
MS, MA	15
PhD	9

Disciplines representing mathematics, chemistry, physics, electrical engineering, mechanical engineering and life sciences.

PILOT SEQUENCE

The course sequence which was chosen was as follows:

I. Vectorial Representation of Variables: matrix formats; manipulations; vectorial products; orthogonality; independence; Fourier Series; Laplace representation convolution; Walsh Functions.

The intent here was to develop a base communications in the course, to set the context of terminology and to introduce the sequence to a group which had indicated strength in the topical area. Applications were treated, homework solutions and several representative journal reprints were distributed through the month, between ensuing sessions.

II. Linear System Variables: convolution; Laplace Manipulations; applications to linear differential equations; damping considerations; impulse responses; system flow diagram; Z Transforms; sampling; numerical methods: Gauss' elimination, matrix inversion.

The goal here was to backtrack into the previous session, held a month previously and to apply the earlier developed tools to simple linear systems. Some linearization schemes were rationalized; sample applications were treated in class to varying depths, generally on a deterministic basis.

III. Probability and Statistics: concepts of discrete and continuous variables; sample space; union; intersection; independence; definitions; density function; distribution function, expectancy operator; moments; confidence limits.

It was hoped here to develop tools for treating probabilistic problems. The attempt was to tie in the discrete abstract variable to several physical situations. Applications were framed to repeat the use of material of the sessions.

IV. Stochastic Processes: stationary processes; approximations to Gaussian; filtering and averaging; correlation; convolution; cross-correlation; covariance matrix; power spectral estimates; bandlimiting effects.

The intent in this session was to relate single continuous variables to the array of tools available to handle generalized data bases. Points of relevance were made to tie in the preceding sessions to space-time variables found in a number of disciplines. Experimental data was developed in handouts and related to different distributions for signal and noise.

V. Stochastic Processes: general review and exercise of modeling tools presented to date; concepts of signals and interference; properties of space and time variables in single dimension case; conditional probability.

Feedback at this point showed that the pace of preceding sessions was too fast. It was attempted to recapitulate cumulative material.

VI. Detector Subsystems: one dimensional signal and noise; detection; decision threshold; optimum processing; receiver operating characteristics; interference effects from ambient noise, system noise, doppler, reverberation, channel uncertainty in a variety of applications.

It had been hoped here that a consistent approach on a set of commonality subsystem functions could be made for ensuing sessions. The detection function is the most common across a variety of disciplines with applications examples in biomedicine, radar, communications, acoustics, optics, and in seismics.

VII. Detector Subsystems: optimum detection; prewhitening; Markov noise; detectability criteria; coherent processing; energy detection; confidence measures; Students' t Test.

Continued work on detection functions.

VIII. Space-Time Processing Subsystems: multisensor arrays; signal and noise matrices; prewhitening; matched filters; detection; averaging schemes.

The linear array and its variations was the central model for two sessions on spatial subsystems. This had been cited as an area requiring emphasis earlier.

IX. Spatial Processors: optimal arrays; lobes in time and space; coherency; detectability for several configurations; near field/far field considerations; non-planar wavefronts.

Intent here was to bring in the cumulative set of modeling tools to a group of spatial applications.

X. Servomechanism Subsystems: Linear models; closed loop and open loop response; root locus; Bode and Nyquist criteria; optimal control; common nonlinearities; phase-plane approach.

This was an area shown strong on the initial poll. The intent here was to give a generally deterministic treatment to this common subsystem. Wiener Hopf and Kalman filtering were treated.

XI. Modulation Subsystems - Analog: amplitude, phase and frequency modulation models; deterministic vectorial and frequency models, noise consideration in design; sideband considerations; convolutions; demodulation schemes.

The goal was to establish here a base for definitions and for common communications with the class treatment. A strong indicator had been shown in the poll for this area.

XII. Modulation Subsystems - Pulsed: PPM, PCM, PWM, etc. and other pulsed models were treated. Relationships between deterministic and band noise-limited cases; system noise and environmental noise budgets.

Second part of modulation treatment.

PRELIMINARY CONCLUSIONS

An evaluation of the first running of this sequence will not be complete for several months. Several qualitative judgments are apparent and will likely be supported by firm data:

1. The collated material represents an excellent in-house reference aside from the detailed class notes on the topical area. It is hoped that this may be built upon, particularly with several representative disciplinary applications in each section.

2. Engendering interest in homework is a challenge. Alternate schemes that appear viable are either 20 short (10 minutes) problems or perhaps 5 half-hour problems. Homework was intended to cover about 6 hours at the beginning of the course.

3. A goal for each section might well be to bring the student to a level of competence in the topic where the technical literature was readable to him. A cross section of this representative material can use further work.

4. Attendance was a continuing fight, offset only by continued personal contact. Better schemes for maintaining attendance are needed in a voluntary environment.

5. "Cultural" differences are noted in the educational sources; physics, mathematics and engineering form a group within which communication is fairly easy. Those with chemistry backgrounds form a separate group as do those in the life sciences.

6. The use of an outside "expert" is a good mechanism to program around sensitive ~~to program around sensitive~~ group feelings within an organization.

7. The chalkboard-pictorial development is the better approach to the problem posed by the vast amount of material required to be covered.

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